Introduction to Lab Instruments - ECE431

1 Introduction

This first experiment is a review of very basic concepts in Electrical Engineering, done with the help of common instruments found in a lab. In other words, you will probe, in practice, some concepts seen in theory. In the process, you will review some features of the instruments which you will use in all courses in Communications and Digital Signal Processing. In most experiments, you will simulate a system, implement it on hardware and test it with actual signals and instruments. Though this experiment appears to be rudimentary, what you practice here will be used in all future experiments.

You will review the time domain and frequency domain representation of two types of signals: sinusoids and pulses. You will use three types of instruments:

- An Arbitrary Signal Generator;
- An Oscilloscope;

2 Suggested Practice and Reading

As a learner, you will benefit most from the practice in this lab by avoiding the automatic settings of the instruments. You, as an Engineer, must understand what you need from the instrument prior to letting the instrument choose it for you. This is to say that you will benefit from learning how to set the instrument first (this should take about three experiments) and only then go for the automatic features. If you can explain what the automatic features do, go ahead and use them.

There is no standard background reading to prepare you to use the instruments. Your best option is to explore the instruments either during the experiments or at the laboratory in your free time. A good reference is [1], in particular the second half of the book, which is dedicated to explaining some of the instruments found in a teaching lab. The websites for manufacturers such as Agilent and Tektronix do offer literature about their instruments, which may be helpful. Manuals for the instruments [2] [3] [4] are available both at the websites and at the lab.

3 The Arbitrary Signal Generator

In this lab you will use the Tektronix AFG3021. It is called *arbitrary* because it allows for waveforms to be designed and edited either on the instrument or on a computer, and then loaded onto the

instrument. Some of your experiments will utilize arbitrary (i.e., made up) waveforms. Below are two settings which you will need throughout the course.

3.1 Setting the Output Impedance

Since you will implement your systems on a DSP platform, all your input signals will be presented to an analog-to-digital converter prior to being processed by the DSP. The input of the converter is a high-impedance input. By default, your signal generator assumes a 50Ω impedance at their output. This is to say that you must adjust the output of the signal generators to "see" a large impedance. This is done by choosing a *High Z* output option, as described below.

3.1.1 Tektronix AFG 3021

- Turn the instrument on [1]. From the front panel, press Sine. You will see on the bottom right corner of your screen a menu labeled *Output Menu*. Press on the corresponding button. Another menu will appear, in which you will find *Load Impedance*. Press on it, and you will have three options. Select *High Z*. From this point on, your instrument is set to see a high impedance load on its output. To return to the main screen, just press on Sine again.
- Make sure that the **Output ON** button is lit (if it is not, press it). It is located right above the BNC output connector. Otherwise you will not have a signal. Note that the **Output ON** button is lit on Figures 1(a) and 1(b). When the output is **ON**, and the output impedance is set to high, the message *Load High Z* will appear on the top right corner of the screen.

3.2 The Tektronix TDS 2012 Oscilloscope

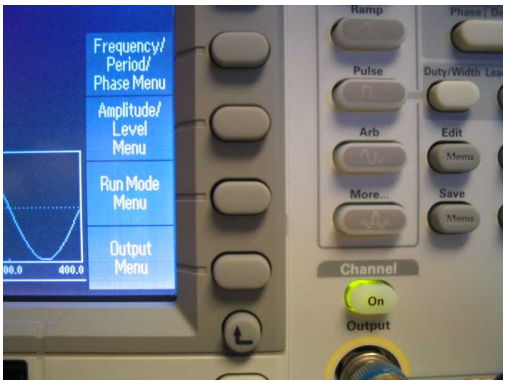
This section will describe some features that if not understood now will potentially cause you to waste precious time during the experiments. These are: the trigger, the MATH/FFT function and the use of cursors for measuring voltage, time, amplitude and frequency. Just as a reminder, whenever you are in the lab, try very hard to avoid pressing the *Auto Set* button. Yes, it is convenient and very popular, but you will not learn as much about the instrument if you always use it. Students tend to assume that whatever is displayed after this button is pressed must be the truth. Always read the numbers and see if they make sense. The trick is to *know what to expect* from the instrument. The general rule is: if you understand what the *Auto Set* button does to get the readings, go ahead and use it.

3.2.1 The Trigger

In general, when you connect a signal source to your oscilloscope the signal "runs" across your screen. In order for you to take a reading, you should make it stop. The proper way to make it stop is to set up a voltage level at which the oscilloscope starts to collect and display the signal. In other words, you should set up a trigger point. This is done by pressing the *Trig Menu* button

[1] it happens

(a) Pressing Sine (Output ON)



(b) Finding Output Menu (Output ON)

(c) Selecting High Z

Figure 1: Tektronix AFG 3021

found at the right-most portion of your front panel, right under a rotating knob. As you press it, a soft menu appears on the right side of the display. Select the trigger *Source* (i.e. channel 1 or 2 – we will not use any other), and a small arrow will appear further to the right of the display. The colour of the arrow is the same as the channel chosen as the source. This arrow indicates your trigger level. Rotate the knob that is over the *Trig Menu* button, and the arrow will move. Position the arrow *within the voltage span of your signal*. This will make the signal stop on the display. Note that the signal continues to be collected and displayed, but it is now steady on your display. If the signal changes in amplitude, frequency, or a feature appears, the display will show it.

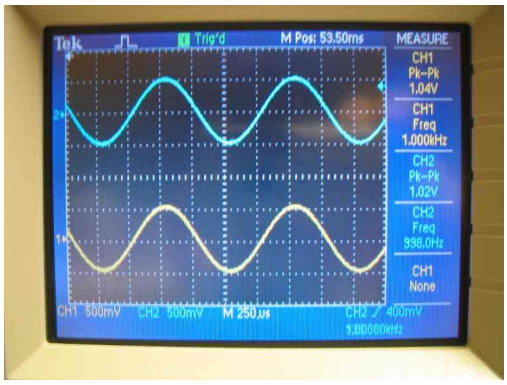
The improper way to make a signal stop is to press the *Run/Stop* button. In the exercise section of this document you will do an exercise to understand why using *Run/Stop* will not be appropriate.

3.2.2 The Math/FFT Function

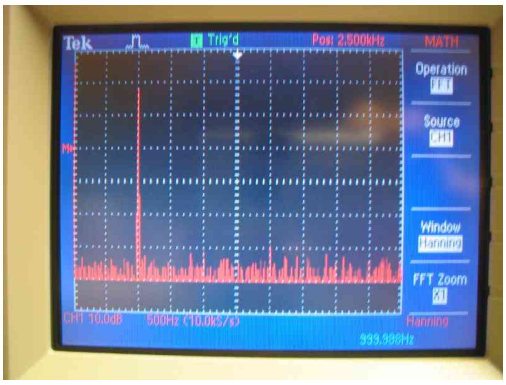
This scope allows you to see your signal in the frequency domain by means of an FFT operation. You can select the *Math* mode by pressing a big fat red button right in the middle of the instrument.

Figure 2: Big Fat Red Button – Math Mode

Figure 3 below shows you the time domain for two input channels and the corresponding frequency domain for one of those channels. Both inputs are a 1KHz, $1V_{pp}$ sine wave.



(a) Time Domain: Two channels



(b) Frequency Domain: One Channel

Figure 3: Tektronix TDS 2012 Oscilloscope

After pressing the *Math Menu* button, you must select what type of operation you want the instrument to perform. For the case of an FFT, you also must select the channel (*Source*) that you want to display. Figure 3(b) is showing the FFT mode for Channel 1.

On FFT mode, the horizontal control works "opposite" to its time domain operation. This is to say that if you want to "increase" the Hertz per Division reading you should turn the horizontal scale knob *clockwise*. In this case, what the instrument is actually doing is selecting a different sampling rate for the input at every click of the horizontal scale knob. You should be careful when using this knob to zoom in, as you may end up with aliasing depending on the type of signal you have (this will likely happen in the exercise section below).

The proper way to zoom into the signal in the frequency domain is to use the FFT Zoom soft

key. Note also that as you turn the horizontal scale knob, at the bottom of the screen the number displayed changes, as it represents the horizontal scale units of Hz per Division. Figure 3(b) shows the frequency component at 1KHz.

3.2.3 Using Cursors

In order for you to perform specific or relative measurements between points of a signal, the instrument allows you to place cursors on the desired points, and presents you with the values at each cursor and the calculation for the difference between the cursors. Cursors can measure differences in time (vertical cursors) and amplitude (horizontal cursors), or in Math mode they can measure differences in magnitude and frequency. After pressing the *cursors* button on the top part of the front panel, you will be presented with a menu to select the signal source (Channel 1, 2 or math) and the type of measurement you want.

3.2.4 Using the *Measure* Feature

The *Measure* button is found on the top part of the front panel. This feature is very convenient, but you should try to develop an intuition whether the numbers displayed make sense. This usually comes with practice. For instance, if your measured output from the DSP board is a 20 V_{pp} sine wave, it should be obvious that this makes absolutely no sense. The power supply feeds the board with only 12 V_{DC}, and the output of the codec cannot handle signals greater than 2.7 V_{pp}. In that case, consider that maybe your 10x probe option is on! If you have a rough idea of what to expect, you will question the displayed value right away. Again, knowing what to expect is very important.

To use the feature, press on the *Measure* button. A soft menu will appear on the right area of the display. You must select the *Source* of the measurement (i.e., channel 1, 2 or Math), and the type of measurement (V_{pp}, V_{rms}, frequency, etc.) When you select it, the measurement will also appear on the right side of the display. Keep in mind that if the 10x, 100x or 1000x probe factor is set, then the measurement will be scaled by it. To disable it, you must go to the channel menu (*CH1 Menu*, for instance) and disable the probe factor.

3.3 Exercise

Now that you are an expert in the use of the signal generator and the oscilloscope, you must do a few exercises to consolidate what you have learned so far. Start by connecting the signal generator directly to the oscilloscope. Make sure you connect the proper output of the signal generator to the oscilloscope (if you want a sine wave and you see a square wave, something is wrong).

3.3.1 Generating, Displaying and Measuring a Sine Wave

Set your signal generator to output a $1V_{pp}$, 1KHz sine wave, and connect its output to the inputs of the oscilloscope using a T connector and BNC-to-BNC coaxial cables. On your oscilloscope, do the following tasks:

- Make the sine wave display on the screen, then make it stop using the trigger;
- Measure its amplitude and frequency in the old fashioned way (i.e. "eye-balling"), by using the *per division* numbers shown on the display. Write your reading down;
- Measure amplitude and frequency using the *Cursors* (horizontal and vertical);
- Measure amplitude and frequency using the *Measure* function of the scope;
- Compare the numbers.

Now set your oscilloscope to display the frequency domain by pressing the *MATH* button. From now on, the amplitude is displayed in dB, with $1V_{rms}$ as the reference. Now do the following:

- Measure the amplitude and frequency of the sinusoid by inspection (eye-balling);
- Measure the amplitude and frequency using cursors;
- Calculate which amplitude value of the sinusoid would give you 0dB. Change the amplitude on the signal generator to the value you have calculated and verify that the amplitude on the oscilloscope is 0dB;

Just for your own entertainment, turn the trigger off (or set it to a wrong value) and make the signal run across the display. Now press the *Run/Stop* button. Great; the signal has stopped. Now disconnect the input to the scope, or turn the signal generator off altogether. You will see that your signal is *supposedly* still there, when it no longer exists. This is why you should avoid this button, unless you are trying the "catch" a feature that happens every once in a while on your signal, such as a glitch, a sudden variation or a spurious noise burst.

3.3.2 Generating, Displaying and Measuring a Pulse

On your signal generator, select *Pulse*, and set your output to be a $1V_{pp}$, 1KHz pulse with 10% duty cycle. This represents a short, "fast" pulse. When you are sure you have the right signal displayed on the oscilloscope in time domain, press on the *MATH* button and switch your display to the frequency domain. You will explore the frequency domain representation of a pulse in this section.

From your knowledge of Signals and Systems, you should know what to expect from the frequency domain display. About 90% of students say "it's a sinc" when asked what a square wave looks like in the frequency domain. That is what the math says, and it refers to the amplitude envelope formed by the frequency components of the signal. In general, when you use the oscilloscope to display the frequency domain, it will perform a Fast Fourier Transform (FFT) on the signal, and will display the amplitude in terms of power (i.e., no negative amplitude) and will display only the *positive* frequency components. This is to say that your display will appear a little different from what you have seen in the textbook, even though they are, in fact, the same.

Follow these steps:

- Display the frequency domain components of the 10% duty cycle pulse, and observe the envelope. Explain to yourself how this amplitude envelope represents a sync function;
- Change the duty cycle of the pulse to 50%. You now have a square wave (50% of the time "on" and 50% of the time "off".) Find the appropriate display for the the frequency domain components. Explain to yourself what they represent, and whether they do follow the same sync function envelope;
- Measure the amplitude and frequency of the four first components of the square wave spectrum. Calculate these values (from the theory) and verify that they match.
- Which of the two pulses requires a wider bandwidth (or spectrum) to be transmitted: the fast one or the slow one?

4 Conclusion

The experiment today lead you to explore the instruments that you will use extensively in the lab. It also required you to explore very basic notions of time domain and frequency domain for two types of signals which are widely found in the theory.

References

[1] P. Kumar, *Digital Signal Processing Laboratory*, CRC Press, 2005

[2] Tektronix, *TDS1000 and TDS2000 Series Digital Storage Oscilloscope - User Manual*

[3] Agilent Technologies, *Agilent 33220A - 20MHz Function Arbitrary Waveform Generator - User's Guide* Agilent Technologies, Inc. 2003

[4] Tektronix, *AFG3000 Series Arbitrary/Function Generators - Quick Start User Manual*